When Complexity Exceeds the Capability to Understand It

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The Big Picture is …

- Broad knowledge of the big picture is important in order to minimize the chance of missing details that result in costly risk.
- Details are important for forming an accurate big picture.
- Details are rarely isolated from each other.
- Active purposeful feedback is needed back and forth between the big picture and the details to fill in the details and to have the right big picture.

The Jigsaw Puzzle Analogy

- Think of how one solves a jigsaw puzzle
  - One usually has a picture on the box
  - One examines each piece relative to the overall picture to determine its approximate location
  - One examines the boundaries of each piece to see how they fit together
  - There can be trial and error when details aren't clear enough
  - As the whole picture is formed, some of the fuzzy details fall into place.

Sometimes We Don't have the Big Picture, or It is Not Correct

- When the big picture is missing, it can be constructed from the details, but as it is being formed, many false turns can be taken resulting in much frustration.

- In Systems Engineering, the Big Picture is the Customer's Problem or Need.
  - Sometimes the customer does not know what they really want.
  - Many times, there is more to the picture than the customer knows or cares about.

Where is this headed?

- The Complexity Issue
- Illustrations of the Problem
- Consequences of the Problem
- The Systems Engineering Process
- Developing a Solution
- What to Do in the Near Term
- What to Do for the Long Term

Complexity in Society

- “Complexity is perhaps the most essential characteristic of our present society. As technological and economic advances make production, transport and communication ever more efficient, we interact with ever more people, organizations, systems and objects. And as this network of interactions grows and spreads around the globe, the different economic, social, technological and ecological systems that we are part of become ever more interdependent. The result is an ever more complex "system of systems" where a change in any component may affect virtually any other component, and that in a mostly unpredictable manner.”

Complexity and Philosophy, Heylighen, Cilliers, Gershenson (2006)

Complexity in Systems Engineering

- "For the purpose of comparing systems today and in the future, complexity can be considered as a measure of how well knowledge of a system's component parts explains the system's behavior and also by the number of mutually interacting and interwoven parts, entities or agents."

INCOSE Systems Engineering Vision 2020, Sep 2007

Complexity of Systems is Increasing

- More capability in smaller packages
- Greater interconnectedness of multiple systems
- Greater machine autonomy
  - Adaptability, learning, etc.
- More outsourcing / larger teams
- Faster development turnaround

In the Engineer's World, Greater Complexity Leads to …

- Greater use of complex components
- Increased use of automation systems in the design process
- Less intimate knowledge of incorporated technologies by the designers
- Less knowledge and understanding of system idiosyncrasies
- Less control of boundary conditions

- Resulting in:

  Greater potential for hidden problems and mistakes

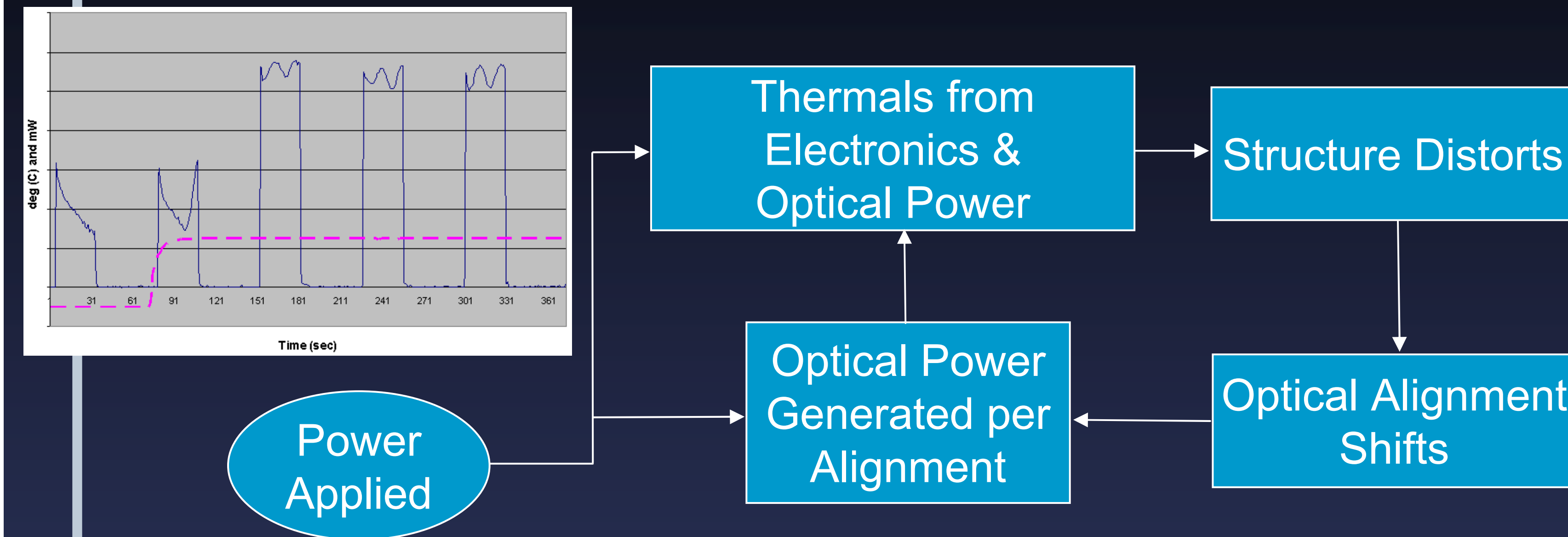
Assumptions and Generalizations Typically Fill the Gap

- When intimate knowledge of a component, assembly, subsystem, etc., has not been established, assumptions and generalizations are usually made based on existing documentation and what is thought to be the intent of the item.
- i.e., the ideas about the way the item fits into the bigger picture are formed, whether right, wrong, or incomplete.

How Problematic Complexity Shows Itself Today (at least in my job)

- Sensor performance is often approximated.
  - Real world has more variability and subtleties than typically modeled.
- Complexity embedded into FPGAs, software, etc.
  - Engineer quickly loses grasp of the interacting details when off the project for as short as a month.
  - Simulations often not always able to consider real-time fully interactive details.
- Bugs in COTS parts used in a different application.

Lasers are a Good Example of Inherent Complexity



- Chaotic / Complex behavior is dependent to some degree on the:
  - Technician who built the laser,
  - The component details,
  - The environment the laser was built in
  - The previous cycle testing that was conducted

Costly Failures Can Result From Missing Details within Complexity

- Debugging process is lengthy and confusing.
- Problems discovered late can result in redesign, cost and schedule overruns.
- Recalls of systems
- Catastrophe, property losses & death

The Risk of Consequence Increases with Complexity

- Added complexity → less understanding
- Past consequences from missing details:
  - Space Shuttle Challenger
    - O-ring problem known, but not well communicated.
  - Hubble Telescope Primary Mirror
    - Aberrations had been previously detected, but ignored.
  - Airbus 330 Flight Computer Issues
    - Faulty data inputs – ADIRUs and Pitot Tubes
    - "In these fly-by-wire systems, one never really knows if one has checked out all possible combinations of events to make sure that the comuter properly reacts,"

      Hans Weber in Time article June 3, 2009, Mark Thompson.
  - Kalman Filter Shutdown
    - Personal story …

Correctly understanding complex systems has benefit beyond typical engineering projects

- Real world has many variables, some quite subtle, yet significant (chaos)
  - Economics
  - Morality
  - Drug interactions
  - Food additives & processing
  - Electromagnetic health hazards
  - Social systems

Drug & Food Interactions

- Studies done on vitamin C, E, and others
  - Some show supplements do nothing
  - Some show supplements are essential
  - Some ignore the quality of the food and the life styles of people today in general
- In general,
  - Vitamins that were artificial and isolated, did nothing.
  - Vitamins that were natural and with other natural ingredients were effective.
- The problem,
  - Drugs, food additives, etc., are often studied in isolation and ignore secondary issues that are actually critical
  - Example, statins for lowering cholesterol
    - Isolated in drug form, greater risk of side effects such as liver damage
    - In natural form, such as red rice yeast, side effects are much reduced but effectiveness are lowering cholesterol is still good.

Indian Ocean Tsunami of 2004

- Was the destruction of this tsunami worse than could have been?
  - No warning system for an area where tsunamis occur, albeit lesser ones.
  - Natural barrier reefs destroyed for shipping channels and fishing.
  - Trees along coasts thinned out for resorts.
  - Sand dunes flattened for beaches.
  - Orphans attracted to tourists at resorts.
- The relevance here, is that even tourism “systems” need to account for anomalies and potential hidden problems.

- http://tsunamisfloods.suite101.com/article.cfm/Indian_ocean_tsunami_2004
- http://scienceray.com/earth-sciences/meteorology/why-the-2004-boxing-tsunami-had-such-a-great-impact/

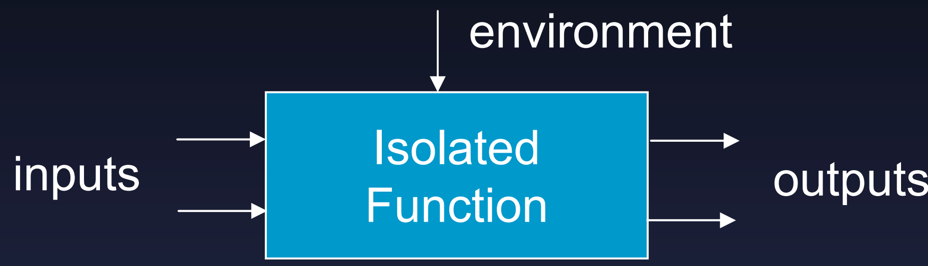
Traditional Systems Methods Are Needed, but Not Enough

- "The traditional scientific method, which is based on analysis, isolation, and the gathering of *complete* information about a phenomenon, is incapable to deal with such complex interdependencies."

  Complexity and Philosophy, Heylighen, Cilliers, Gershenson (2006)

- However, from a practical perspective much still needs to involve the traditional systems process:
  - Functional and physical partitioning and analyses
  - Well defined boundaries / interfaces
  - Thorough testing of components and subsystems
  - Push towards Simplicity rather and away from Complexity as much as possible

Clearly Defined Boundaries Help, But Not So Easy as Complexity Increases.

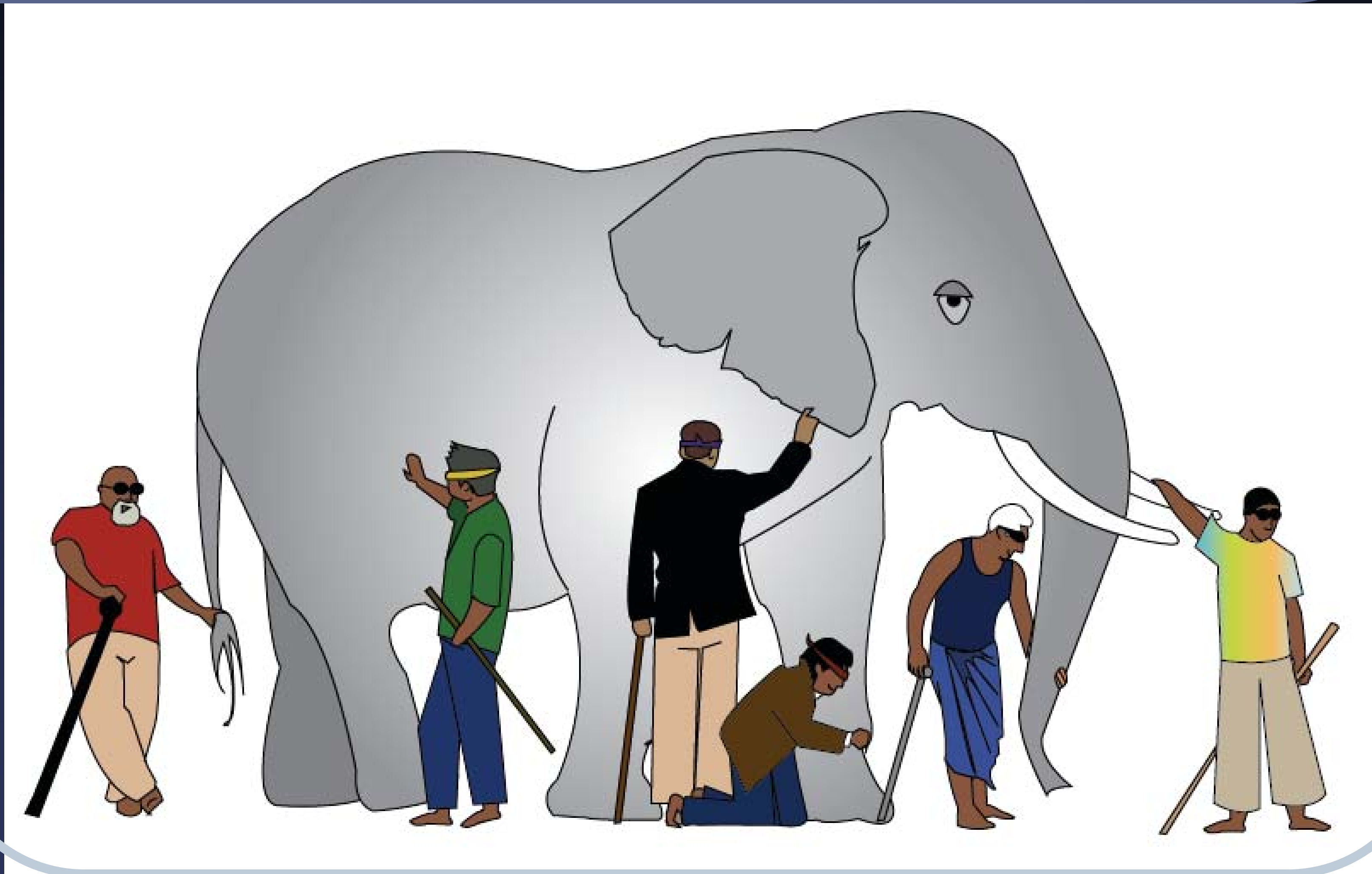


- Behavior isolated within the box as a closed system can only be affected by the inputs and conditions applied to it.
- No need to model details at a lower level if all effects from external stimulus can be covered in the functionality.
- But, if components within can be affected by secondary affects from other components, such as through generation of heat, EMI, etc., then there is potential for an insufficient model.
- Simulation at a level requires good understanding at that level, but underlying details could affect higher level combinations of entities where new emergent properties are different than predicted.

How to Understand the Whole

- For the most part, systems today can still be built up through standard processes
- But, to catch potential pitfalls, a holistic approach is needed.
- Models can improve over time and as computing capability continues to increase.
- But even with models, holes, misunderstandings, problems can occur.

Parable of the Six Engineers



Parable of the Six Engineers

Parable of the Six Engineers

- Far east parable is normally told to explain how each is looking at the same thing (God) from a different perspective and thus all views are correct.
- However, each view does not contradict the other views because they are looking at completely different aspects of the elephant and in their limited views, completely missing the boat of getting the Big Picture!
- It is when different people describe the same aspects in conflicting ways that there is a problem.
  - Is it an elephant or a snake?
  - There is quite a difference in how you deal with either.
- Each should be looking at what the others are looking at.
  - The experience and understanding of each needs to be compared with the Big Picture in mind.
  - Each person’s perspective grows,
  - the individual view gets more inline with the Big Picture.

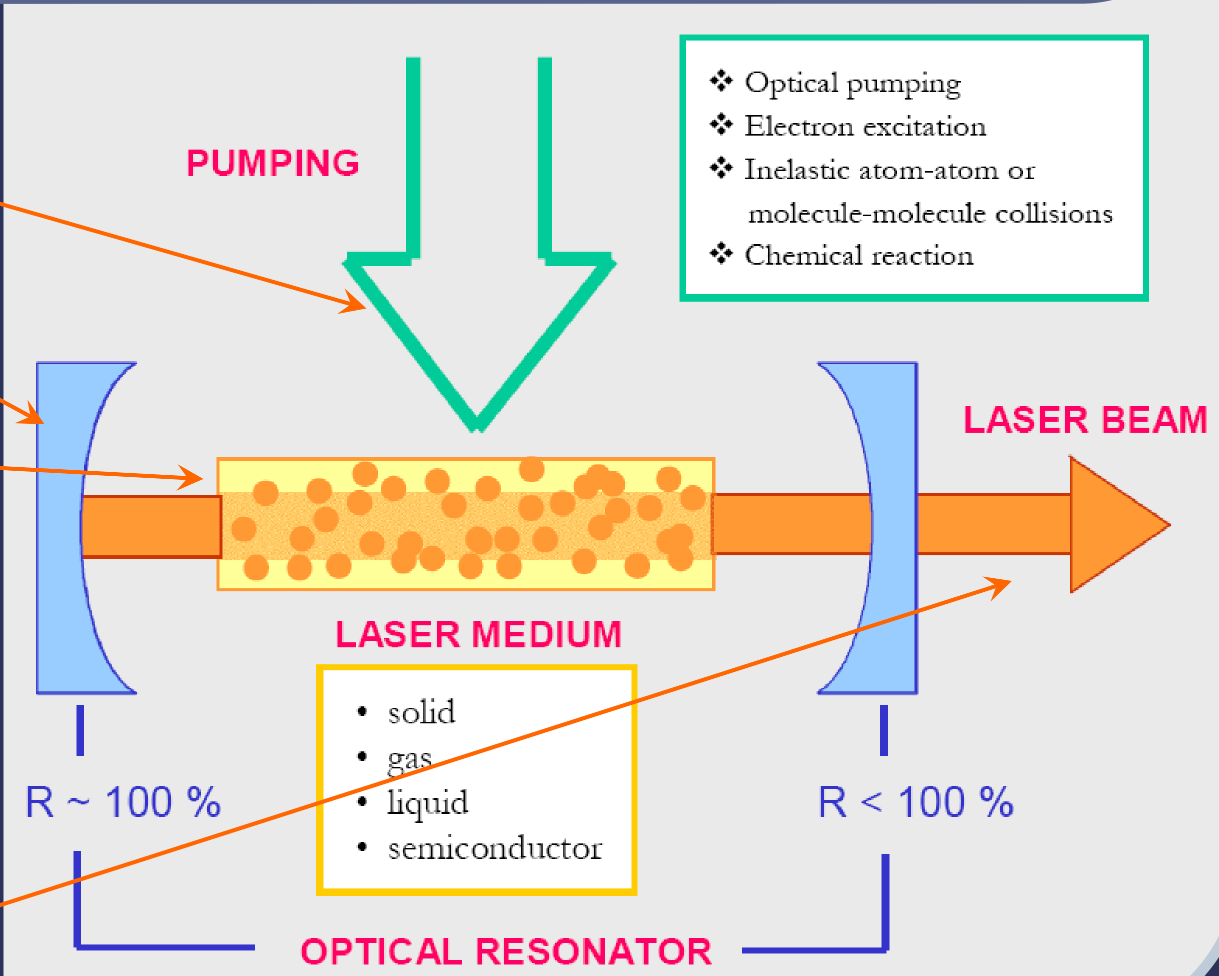
Example of Most Effective Managers and Technical Achievers

- Best managers and technical achievers
  - have broad knowledge and absorb information outside of their own expertise,
  - have detailed knowledge in their expertise,
  - they rely upon experience of others, and
  - they are effective communicators.

Laser Analogy: A laser consists of an energized crystal, mirrors to concentrate the light, and an energizing light source to create a very intense pure coherent beam of light.

Knowledge Laser:

- Energizing Source = Project Activity
- Mirrors = Reality, reflect the light back into the energized crystal
- Crystal is the congregate of experts
- Responsiveness of the crystal is related to the education, experience, and background of the technical team
- Output beam is the coherent knowledge about the system



The activity of each expert interacts with and is influenced by the activity of all the other experts to build up system knowledge.

Reasons for Incoherence

- Most of the problem stems from
  - differences of personal experience,
  - competing goals,
  - differences of depth of understanding of relevant areas,
  - influence of personal egos.
- Overcoming requires:
  - active effort,
  - development of common goals,
  - high levels of experience across most of the team,
  - high levels of active communication.

Near Term Solution – Applies Whether a Technical Problem, Dealing with a Global Economy, or even Forming a Worldview

- Push for simplicity and segment systems as much as possible to maximize comprehensibility
- Small iterative steps towards greater complexity
- Communication
  - Everybody really needs to know what everybody else is doing and why (all the pieces of the puzzle and how they relate)
  - Everybody needs to have an understanding of the Big Picture to know how their part fits within the whole.
- Diversity of reviewers
  - Each looking at the same thing from their own experiences
- Experience – hands on
  - More problems are discovered by "playing" with the system, even if through simulation
- Question the basis of assumptions and be ready to revise as necessary
- Actively looking for unforeseen potential issues
  - Having enough experts involved in the development process increases the probability of pointing out possible problems.

Risk Management is Crucial

- Managing development of complex systems requires active effort, emphasis, and time.
- Greater the complexity, greater the tendency towards disorder or chaos.
- Failure to communicate is likely the number one cause of failure on a project.

Far Term

- Information / Knowledge Systems with database of “knowledge”
- Eventually globally distributed systems will have knowledge entities that can be used to test the myriad of possibilities that could impact a system

Conclusion

- End Goal is to Minimize Risk of Failure
- The Big Picture is essential for correctly capturing and testing the details.
- The details form the correct Big Picture through iteration and feedback.
- Bringing together the collective experience of experts yields the best chance of forming a correct Big Picture and capturing the needed details
  - Most problems in the past have been known by someone who could have helped steer the ship around the iceberg.

References

- Cilliers, Paul, *Complexity and Postmodernism: Understanding Complex Systems.* Routledge, London, 1998.
- INCOSE Systems Engineering Vision 2020, Sep 2007
- Wikipedia – various